Seasonal Variations of Dissolved Inorganic Nitrogen in Budd Inlet, Washington

Jeffrey M. Cox and Suzanne L. Giles
Evans-Hamilton, Inc.

Introduction

The growth experienced by the city of Olympia, Washington and surrounding communities has caused increased demand on existing wastewater treatment facilities. Increased disposal of waste water into Budd Inlet during the winter months from the Lacey-Olympia-Tumwater-Thurston County Wastewater Treatment Plant (LOTT) has been proposed as a partial solution to this difficulty. A 13-month intensive field measurement effort was made to determine the feasibility of this option (Budd Inlet Scientific Study Final Report, 1998). One tool that was created to help assist in this decision was a model that incorporated both water quality and circulation information.

The major historical water quality problem in Budd Inlet has been the development of low dissolved oxygen (DO) concentrations in the lower portions of the water column during late summer and into fall. This condition occurs in the head of the inlet and occasionally extends into the central portion of the inlet as well. Earlier studies attributed low DO levels to a number of factors, including:

1) water entering Budd Inlet from Puget Sound that contained lower DO;
2) a strong thermocline that caused severe vertical stratification;
3) excess nutrients that allowed large plankton blooms to occur; and
4) decay of plankton blooms that increased the demand for DO (WDOE, 1997).

WDOE (1997) documented the dissolved inorganic nutrients limiting plankton growth in Budd Inlet as ammonia, nitrate, and nitrite. Regulation of these nutrients was viewed as the key to controlling plankton blooms and the subsequent low DO conditions. As the most easily controlled input of these nutrients, LOTT was required to implement a dissolved inorganic nitrogen (DIN) removal process, which has been active from at least 1 April to 31 October annually since 1994. During the summer of 1994, WDOE (1997) documented that DIN concentrations in both LOTT effluent and in Budd Inlet were greatly reduced compared to the summers of 1992 and 1993. However, LOTT's contribution of DIN to the whole inlet was not assessed at the time.

To place in perspective the major sources and sinks of dissolved inorganic nitrogen (DIN) to Budd Inlet, the flux of DIN into and out of the inlet was computed for both the whole and inner inlet to form nutrient budgets (Figure 1). The nutrient budgets integrated many of the measurements conducted during the Budd Inlet Scientific Study, including those from current meters, river discharge, sediment fluxes, precipitation, wastewater treatment plants (WWTPs), inlet surveys, and primary productivity experiments.

For this analysis, the pool of DIN was considered to be the DIN residing in the marine waters within either the whole or inner inlet. Sources that released DIN into the inlet's waters include fresh water (rivers, streams, creeks, and rainfall), sewage treatment plant discharges (also fresh water), inflowing marine waters from Puget Sound, and sediments.

The sinks of DIN included marine water exiting to Puget Sound, the sediments, and phytoplankton uptake of DIN. Primary productivity experiments measured the DIN uptake due to phytoplankton growth. These nutrients can then be released to the water column upon cell lysing or become part of the sediment when the cells die and sink to the sea floor. The DIN loss terms were calculated in two ways, including and excluding primary productivity in order to gain a better perspective on the role phytoplankton play in the nutrient dynamics within the inlet.

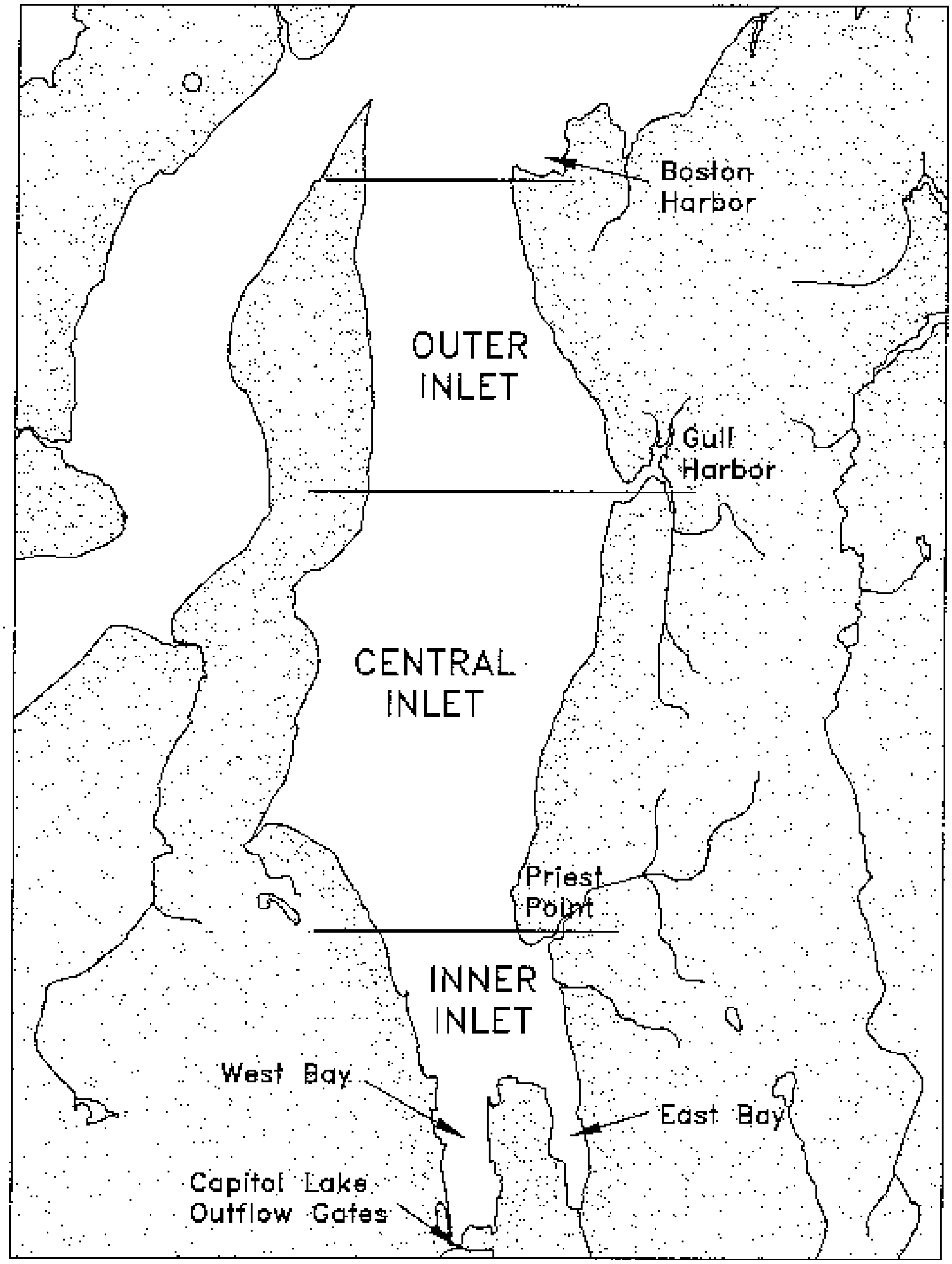

Figure 1. Budd Inlet, Washington methods.

Inputs of DIN were based on field measurements from many different facets of the study. Inlet, benthic, and shoreline surveys occurred twice per month over a 13-month period (Figure 2). In addition, moored meters measured water conditions and movements continuously over the study period (Figure 2). Wastewater treatment plant and freshwater DIN loadings were calculated from shoreline survey DIN samples and daily flow rates computed using a freshwater flow model. Puget Sound DIN loadings were computed using DIN concentrations measured in the incoming marine water and monthly net transport values obtained from the current meters (Ebbesmeyer and Coomes, 1998). DIN from the sediments were determined from benthic flux measurements and the bottom surface area at mean lower low water (MLLW) (Uhlenhopp and Devol, 1998).

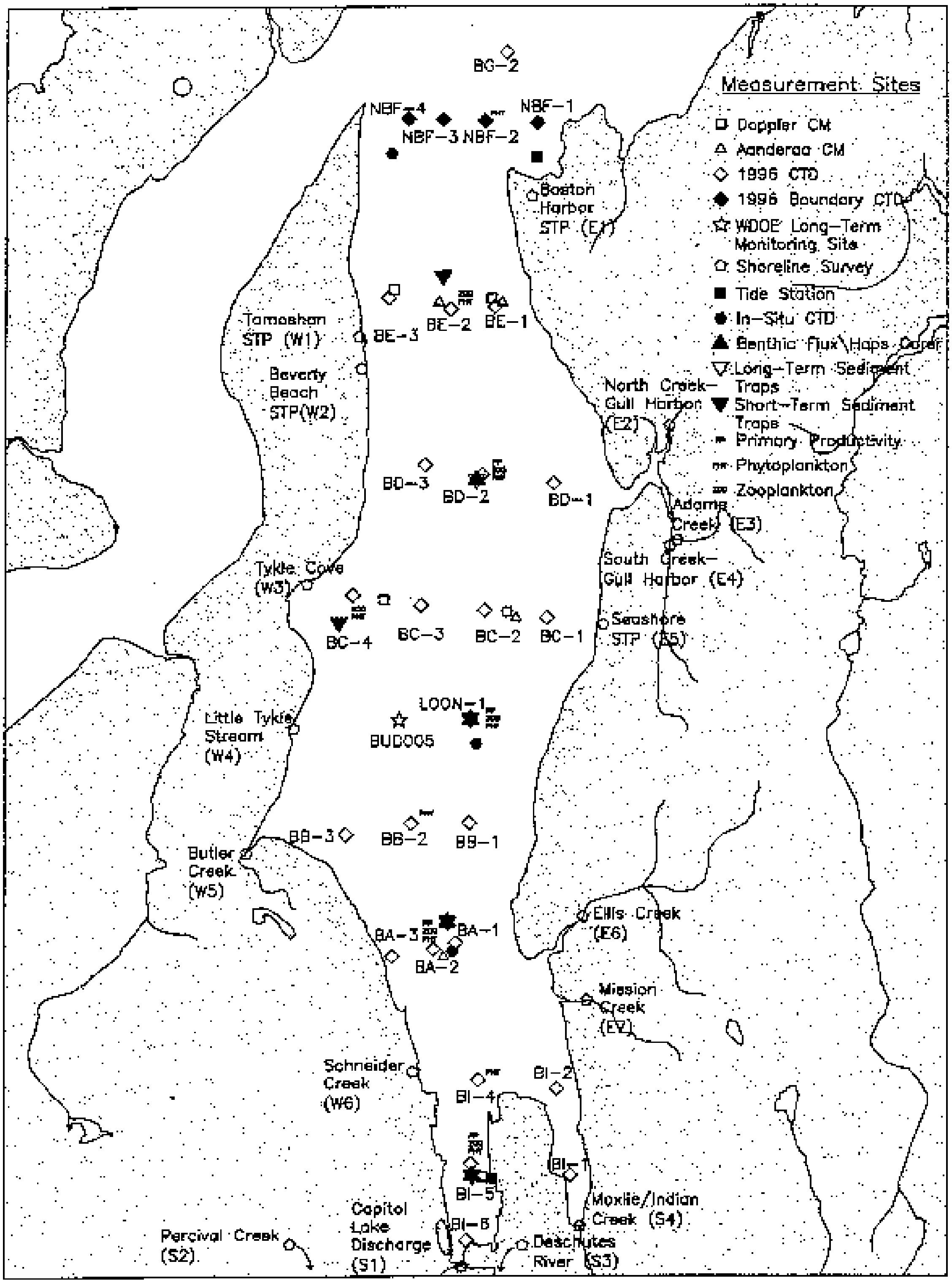

Figure 2. Budd Inlet Scientific Study measurement stations.

Outputs of DIN were computed in a similar manner to the inputs. Puget Sound DIN outputs were calculated by multiplying the net transport of the outgoing, upper layer at the mouth of the inlet by the DIN concentrations within that layer. Sediment DIN outputs were determined in the same manner as the sediment inputs. Phytoplankton uptake was measured during primary productivity experiments, which occurred twice per month for nine months; these rates were then integrated over the water column and multiplied by the area for the different portions of the inlet at MLLW (Newton et al., 1998).

Results

Sources of DIN

Figure 3 shows the average rate of DIN input from each source for the whole and inner inlet by month. The total amount of DIN entering the whole inlet ranged 3-fold between the wet winter months (November 1996–January 1997) and dry summer months (July–September 1997). Similarly, DIN inputs to the inner inlet varied by a factor of four between the wet and dry seasons. The ratio between the individual months of January and August was nearly five-fold.

The main source of nutrients to the whole inlet in all months was Puget Sound (Figure 3, top panel; Table 1). Likewise, it was the primary source for the inner inlet except in August 1997. The inner inlet received nearly all of the nutrients entering the inlet from freshwater sources, including wastewater treatment plants, rivers, and streams. Rainfall and sediments contributed more DIN directly to the central and outer portions of the inlet versus the inner inlet due to the larger surface area in those segments of the inlet.

Because the inner inlet received most of the incoming freshwater nutrients, the relative impacts of these DIN sources on the inner inlet were different than those on the whole inlet. For the inner inlet, Capitol Lake was the second largest source of DIN from November to May, while the sediments and LOTT varied as the third and fourth largest contributors during these months (Figure 4, bottom panel). From July through September, sediments were a larger source than Capitol Lake, with LOTT generally being the fourth largest supplier. The contribution of the sediments is more clearly seen with the large contribution by Puget Sound removed (Figure 4). Capitol Lake added slightly more DIN to Budd Inlet than the sediments during the month of June.

For the whole inlet, Capitol Lake was the second largest source of DIN from December through April with the sediments being the third largest contributor (Figure 4, top panel). For November, and for and May through September, these roles reversed, with sediments as the larger of the two sources. With the exception of the month of August, LOTT was the fourth largest supplier of DIN to the inlet.

LOTT is not a major contributor of DIN to Budd Inlet when compared to the other sources. Throughout this study, LOTT contributed less than 5% of all DIN entering the whole inlet from measured sources. While very small, additional unmeasured sources would further reduce LOTT's percentage. When only the inner inlet was considered, LOTT supplied less than 8% of the DIN. During winter months, LOTT's contribution to the inner inlet typically was 7% or less and during summer was lower than 4%, with the exception of 8% during August 1997. During that month, LOTT's total DIN discharged was the same as during June and September; however, both Capitol Lake and Puget Sound reached their minimum input levels, thereby increasing LOTT's percentage of the total contributions.

To summarize winter to summer differences for contributions from each type of source, the range of the contributions during winter (November–January) and summer (July–September) are shown in Table 1. The year is divided this way because LOTT operates its nitrogen removal facilities from April to October. For the remainder of the year the nitrogen removal facilities operate in a diminished capacity. Note that regardless of season and segment of inlet, LOTT is the fourth largest contributor in most months, ranging between 1% and 8%.

Table 1. Percentage of total DIN loadings to Budd Inlet by source and season

Source	**Whole Inlet**		**Inner Inlet**	
	Winter (Nov. 1996–Mar. 1997)	**Summer (**Apr.–Sept. 1997)	**Winter**	**Summer**
Puget Sound	78–83	60–84	73–78	47–82
Sediments	2–11	6–34	0.4–6	0.7–37
Capitol Lake	7–11	1–8	12–17	3–14
LOTT	2–5	1–3	3–7	2–8
Other inputs	1–2	1–3	1–2	1–5

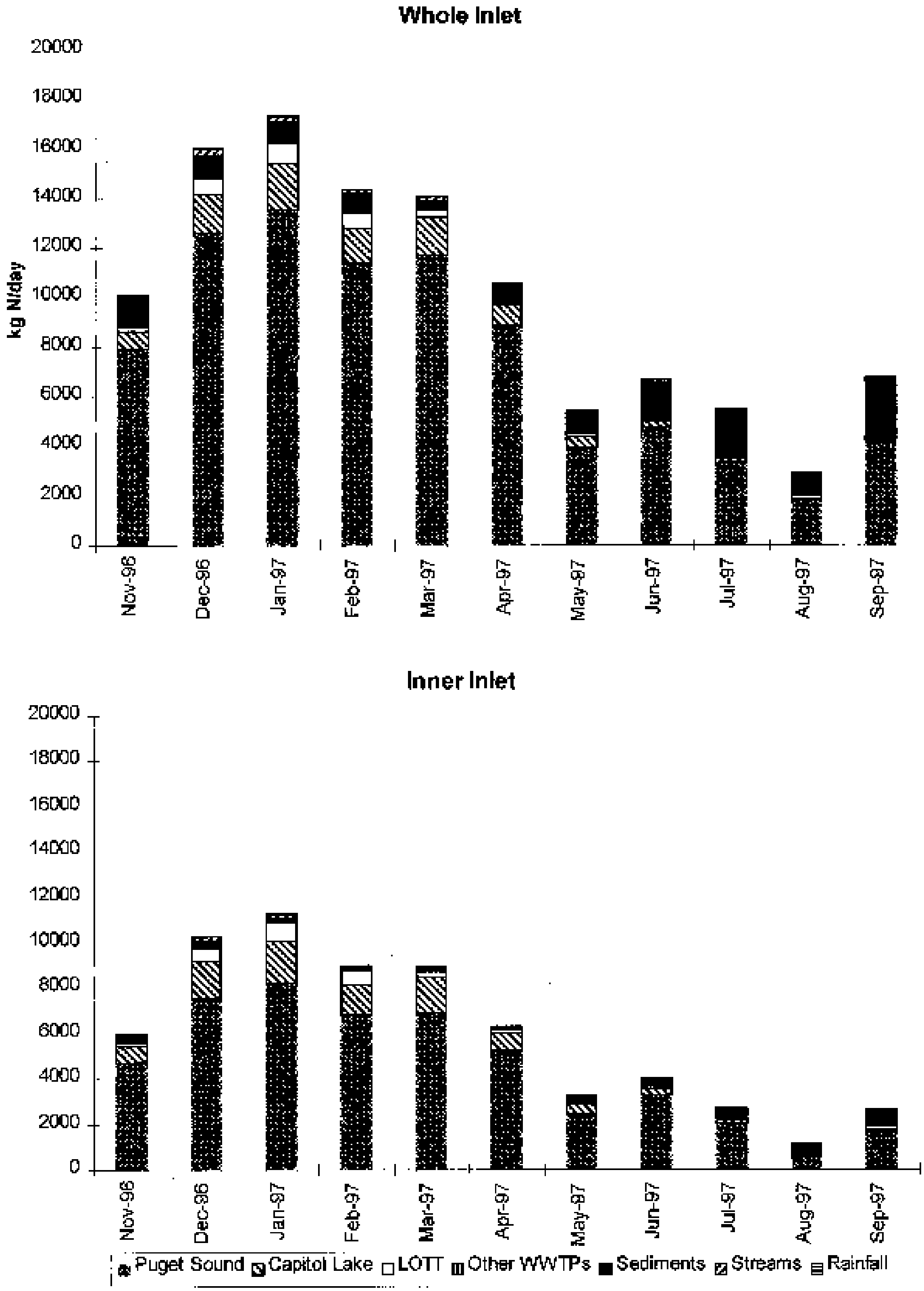

Figure 3. Dissolved inorganic nitrogen loading to Budd Inlet, November 1996–September 1997.

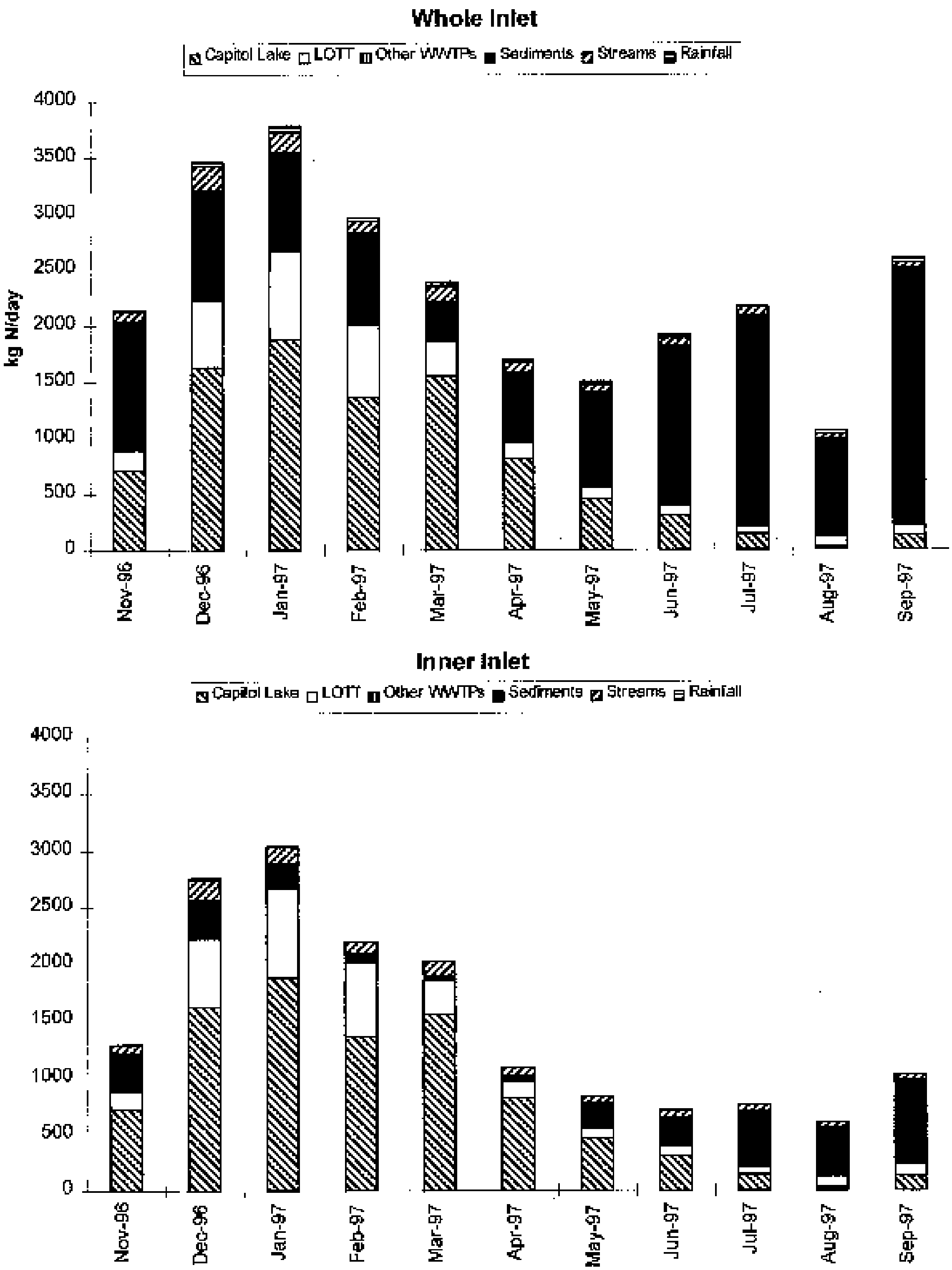

Figure 4. Dissolved inorganic nitrogen loading to Budd Inlet without Puget Sound contributions, November 1996–September 1997.

The sediments played a significant role in the DIN inputs, providing up to one third of the DIN entering the whole and inner inlets during some months. This input was a direct result of increased water temperatures and the loading of fresh organic materials to the sediments from dying plankton blooms. The importance of this organic loading to the sediments was conceptually understood in terms of its effect upon sediment oxygen demand, but not as well documented for its importance to nutrient recycling in Budd Inlet. These recycled nutrients represented only about 22% of the DIN reaching the sediments, with approximately 12% of this nitrogen converted into nitrogen gas and subsequently lost to the atmosphere (Budd Inlet Scientific Study Final Report, 1998).

Sinks of DIN

The sinks of DIN varied by season, mostly due to changes in primary productivity. Water exiting to Puget Sound was the primary DIN sink during the winter months; in contrast, phytoplankton nutrient uptake was the primary sink during the summer months (Figure 5). Upon receiving favorable light conditions in late March and early April, the phytoplankton population increased and began utilizing DIN at rates sufficient to lower concentrations within the water column. As a result, the concentration in outgoing Puget Sound water decreased. In addition, the net transport rate within the inlet began slowing after March as less fresh water entered the inlet during late spring and summer. The combination of these two decreases led to a smaller DIN load out of the inlet. Only a small amount of DIN was lost to the sediments throughout the year. In summary, nearly all DIN loss was due to transport out of the inlet during winter months, while the dominant loss in the summer was phytoplankton uptake.

Balance of Inputs and Losses

The balance of the DIN inputs and losses was computed (Figure 6). In this figure, the additional loss of DIN due to utilization by phytoplankton shows the dramatic influence phytoplankton have over the balance of the inputs and losses, and therefore the resulting concentrations within the marine waters. In general, periods of net inputs correspond to the seasonal periods that DIN concentrations within the marine waters were increasing or remained steady (September 1996–March 1997). Periods of net loss correspond in general to when DIN concentrations decreased or remained at low levels in the marine waters (April–August 1997). Phytoplankton uptake of DIN heavily influenced the balance of inputs and losses during primarily April–September 1997 as expected.

While this balance shows general agreement to increases and decreases of marine DIN concentrations, it is apparent that some future refinement may be necessary. In particular, inputs and losses during December–February should nearly balance, as marine concentrations remained steady during this period. The largest net loss was anticipated to have occurred during April–May when the largest decrease in marine DIN concentrations occurred, rather than August. A decrease in marine DIN concentrations did occur within August, but not to as large an extent as during April. These results suggest two things: 1) that during winter, DIN losses may be underestimated as that is the time of limited sediment flux and primary production data; and 2) that during spring and summer, decay of dead phytoplankton, and the subsequent release of nitrogen back to DIN must be occurring within the water column to a greater extent than anticipated, and therefore not just occurring at the sediments. A term to represent this process was incorporated into the water quality model. Another factor affecting spring and summer rates could be that the DIN input from the sediments and the spatial variability in phytoplankton uptake of nutrients was greater than our measurements allowed us to interpret.

Summary

LOTT does not appear to be a major influence on the DIN dynamics when analyzed in relation to the contributions of Puget Sound, the sediments, and Capitol Lake. LOTT's DIN contribution to Budd Inlet was very small, providing less than 8% of the total DIN entering the inlet. In contrast, Puget Sound was the dominant source throughout the study and contributed between 60–84% of total DIN. The role of the sediments varied more seasonally than other sources, becoming a larger player during the summer months when the role of other potential inputs such as Capitol Lake decreased. Of the freshwater sources, Capitol Lake was the dominant input and had strong seasonal variation. Phytoplankton played an important part in the nutrient and DO dynamics of Budd Inlet by utilizing nutrients in the water column and subsequently returning a portion of these nutrients to the sediments.

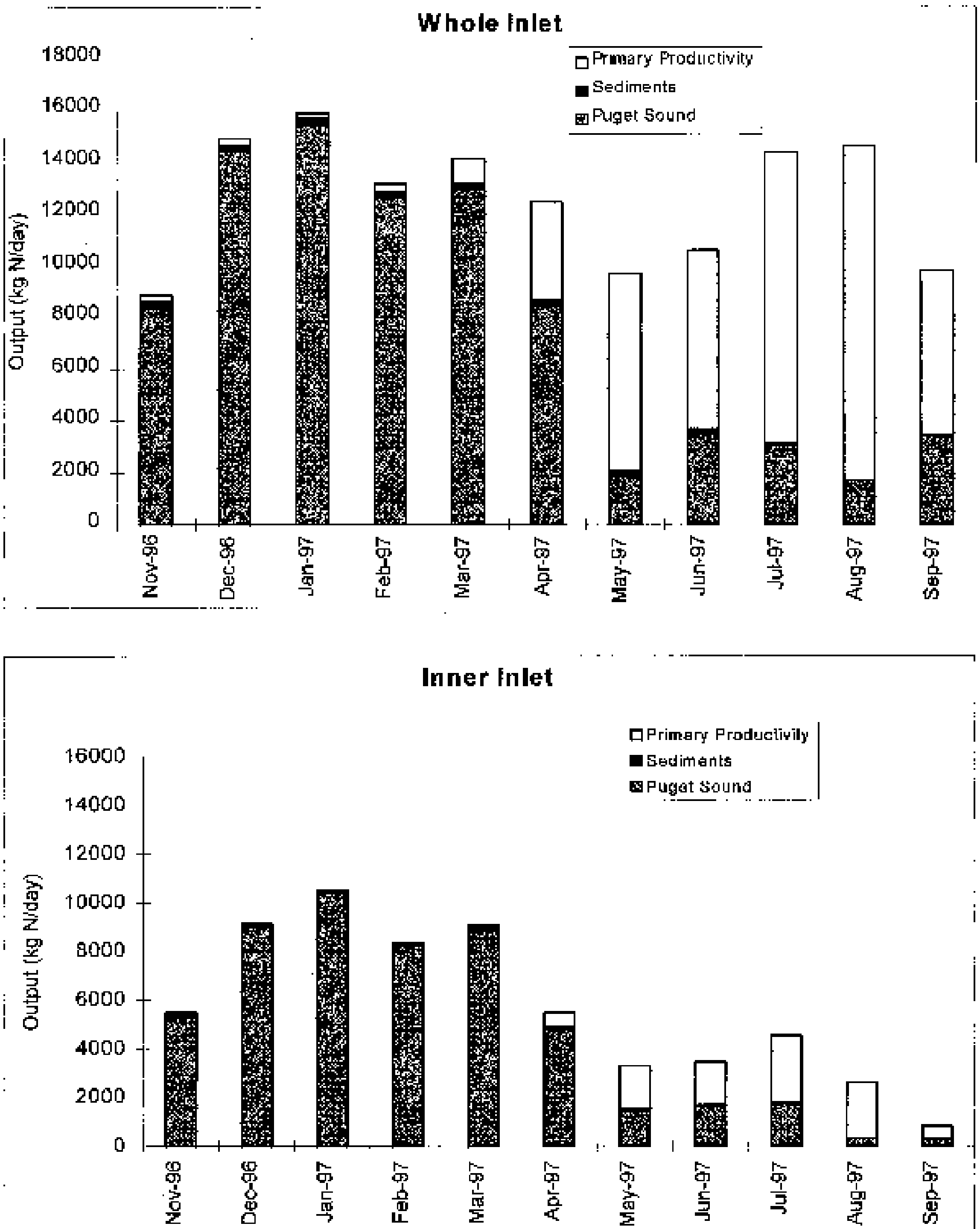

Figure 5. Sinks of dissolved inorganic nitrogen in Budd Inlet, November 1996–September 1997.

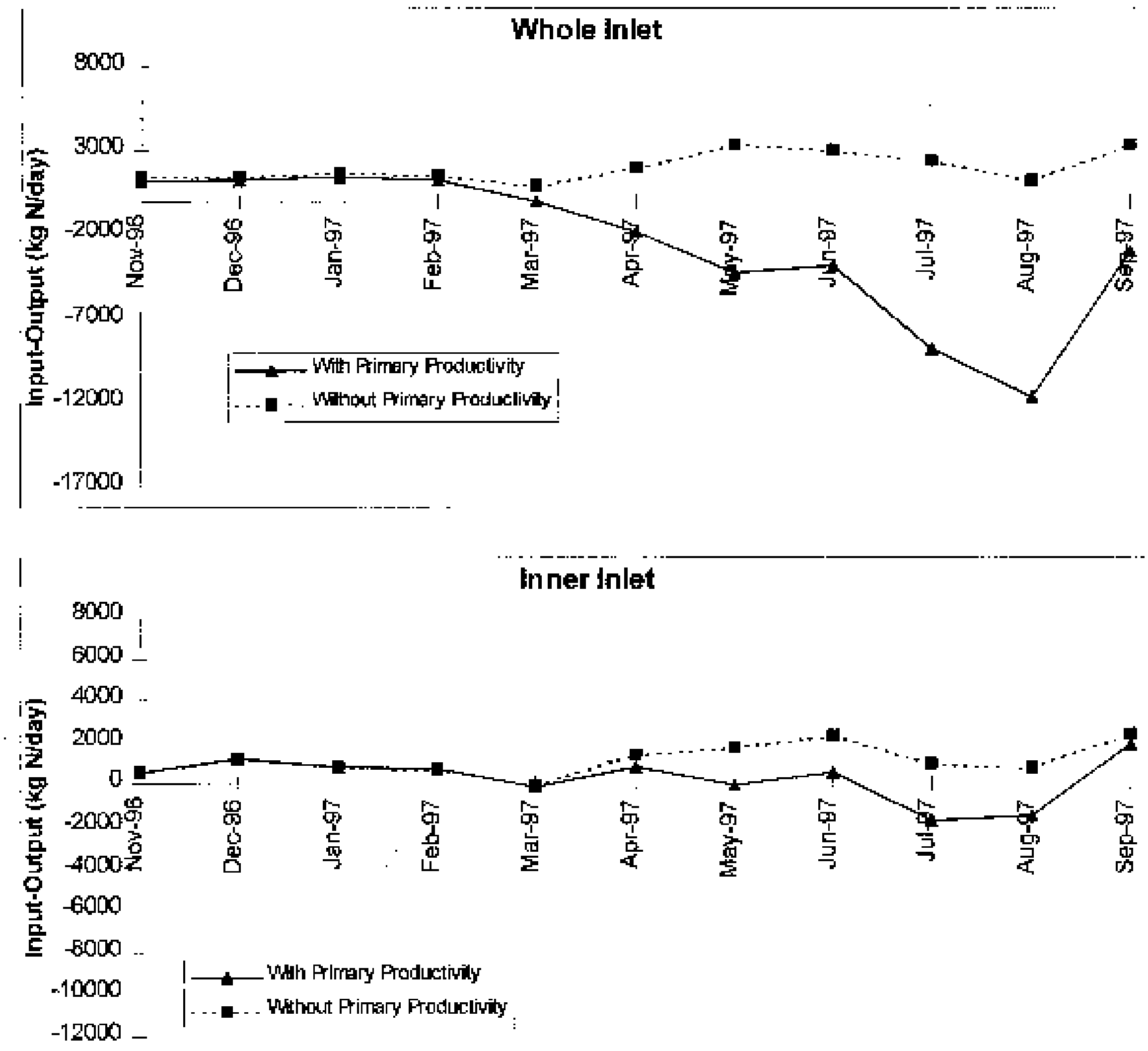

Figure 6. Balance of inputs and outputs in Budd Inlet, November 1996–September 1997.

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